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Propellants, Explosives and Rocket Motor Establishment, Waltham Abbey, Essex

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Technical Report 120

Initiation of Aerated Nitroglycerine in an Eductor

D. G. Tasker   October 1979

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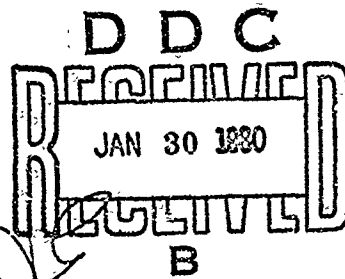
PROPELLANTS, EXPLOSIVES AND ROCKET MOTOR ESTABLISHMENT

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⑥ INITIATION OF AERATED NITROGLYCERINE IN AN EDUCTOR

by ⑪ Oct 79 ⑫ 14

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⑱ DRIC ⑲ BR-70957

SUMMARY

A technique is described for the measurement of the shock wave pressures generated within nitroglycerine (NG), when the liquid surface strikes a steel cylinder. These pressures have been observed in a model of a Biazzi Nitroglycerine Eductor; they are shown to be in close agreement with those theoretically predicted and indicate that this mechanism for the initiation of explosion in NG requires serious consideration.

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CONTENTS

1   INTRODUCTION

On the 11th September 1972 at ROF Bishopton a Biazzi Nitroglycerine
Eductor and its associated plant were destroyed by explosion. A number of
possible causes of this accident were analysed in detail by the subsequent
Court of Inquiry.[1]

The eductor in question had carried out more than 18 000 eductions
before the accident. However certain deviations from the normal procedure
were noted at the inquiry. In particular the contents of the tank had been
left standing overnight and it was thus thought possible that gas bubbles
could have accumulated in the liquid as a result of temperature cycling.
The NG could therefore have been sensitized to the shock initiation of
detonation. Ayerst suggested at the inquiry that the impact of the rising
NG/air interface with the eductor surface could have been the cause of the
explosion. Bascombe[2] examined the possibility of shock initiation from this
cause and by reference to the work of Roth,[3] attempted to quantify the
possibility.

The work described in this report demonstrates that the shock pressures,
generated by the NG/eductor collision, can be measured and are of the same
order as those predicted by Bascombe. These pressures have been observed in
a model of the eductor, and indicate that this mechanism for the explosion
requires serious consideration.

2   THE INITIATION MECHANISM

The Biazzi Nitroglycerine Eductor is basically a water jet pump. The
device is used to convey NG safely from stage to stage within a processing
plant by incorporating the liquid in a water based emulsion. Figure 1 shows
a diagram of the eductor. When the eduction mechanism is started water is
forced through the nozzle of the eductor at a pressure of 0.83 MPa (120 psi).
The resultant high velocity jet of water produces a reduction of air pressure
above the NG surface in the suction leg of the apparatus. The NG column
thus rises towards the nozzle assembly where it eventually mixes with water
downstream from the nozzle. The velocity of the surface prior to impact with
the nozzle is estimated to be up to 4 m s^{-1},[4] although a more recent estimate
suggests that a maximum of 3 m s^{-1} may be more realistic.[5]

The collision of the NG and stainless steel surfaces produces two shock
waves that propagate into the liquid and the steel respectively with equal

shock pressures and particle velocities but different shock velocities. These parameters can be calculated from the well known impedance mismatch formulae,[6] and Equation 2, Section 4. In Reference 2 it is calculated that a shock pressure of 1.9 MPa per unit impact velocity would be attained, ie a pressure of 7.6 MPa can be attained at 4 m s^{-1}.

An examination of Reference 3 reveals that shock pressures of approximately 8.5 MPa are likely to detonate NG containing 1 mm air bubbles and 3.2 MPa for 10 mm diameter air bubbles. Therefore, assuming bubbles of 1 mm diameter or greater are contained by the NG a significant possibility of the initiation of detonation exists.

3   THE EXPERIMENT

3.1   Design of Experiment

The purpose of the experiment was to demonstrate that the shock wave pressure arising from the steel/NG impact, and described by Bascombe, could be generated and measured in the laboratory. To this end it was proposed to build an instrumented model of the eductor.

The difficulties with instrumenting the interior of the eductor, and the hazards associated with the use of NG in the laboratory, necessitated the departure of the model design from that of the original eductor. These changes are insignificant from the viewpoint of the generation of shock waves.

The NG was replaced by distilled water.* The relatively small difference between the acoustic impedances of NG and water is known so that a small correction could be made to estimate the equivalent shock pressure developed in NG.

The design of the experiment was also modified by causing the steel cylindrical eductor surface to move instead of the liquid surface. Provided that the cylinder is moved at the same velocity, 4 m s^{-1}, the initial shock amplitude will not be affected. (The subsequent pressure/time profile will of course be affected but is of no consequence in this experiment since only the magnitude of the initial pulse is of interest.)

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*A small quantity of common salt was added to the water to facilitate triggering of the electronic equipment - this was shown to have no significant effect on the shock wave amplitude.

A sketch of the apparatus is shown in Reference 2. A full scale model of the impacting cylindrical surface* was attached by a Tufnol yoke to the body of a 5 kg drop weight. (See Figure 2.) The model cylinder could be raised to any desired height h above the liquid surface and dropped. The subsequent impact velocity u was then $\sqrt{2gh}$ so that a height of 0.81 m rendered the desired velocity of 4 m s^{-1}. The rim of the polyethylene beaker, used to contain the liquid, served as a brake and checked the fall of the drop weight before the cylinder could strike the piezoelectric pressure gauge.

3.2 Gauge Considerations

It was realised at the outset that the impacting surface of the cylinder would be a thin line, Figure 3, the initial shock thus developed would have relatively little energy in the low frequency end of the acoustic spectrum because of the thin radiating line. For this reason the author designed a high frequency, broad band pressure transducer based on a 37.5 μm thick disc of PZT-5A, a barium titanate/lead zirconate sintered ceramic manufactured by Vernitron Ltd. The shock would also diverge rapidly from such a line source and consequently the pressure would diminish rapidly with distance. The gauge mounting was thus designed so that the gauge depth, d in Figure 2, could be adjusted; by varying this depth the shock divergence could be allowed for.

The signals were recorded directly on a 100 MHz storage oscilloscope, Tektronix Model 7633, amplifier 7A15A. The instant of impact of the steel surface with the liquid was detected electrically using the circuit of Figure 4. The weakly conducting electrolyte and the metal impact surface were thus used as part of a 'contact closure' trigger circuit for the oscilloscope.

The gauge sensitivities were calibrated using an hydraulic apparatus capable of producing accurate relief pulses of 6.8 MPa.

4   RESULTS

The results obtained using the cylindrical impact surface showed that, as expected, the pressure wave diverged extremely rapidly - so rapidly in

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*The impacting surface was modified in later experiments (Figure 2) to
 facilitate pressure measurement, see Section 4.

fact that the gauge could not be positioned near enough to the impact surface to record reproducible signals. The impact surface was therefore changed to that of right circular piston, as shown in Figure 2, of diameter similar to that of the original cylindrical surface.

The physics of the wave radiating from a piston is well known; the pressure wave generated does not diverge until a range of the order of $U_s a^2/f$ is exceeded, the Fresnel zone, after which the pressure wave diverges. (Here 'a' is the diameter of the piston, f the frequency of interest, U_s the wave velocity.) By using a piston surface it was possible to measure the shock wave reproducibly; the initial pressure was unaffected, only the surface area of the impact surface had been increased to facilitate pressure measurement.

The results are shown graphically in Figure 5 for various gauge depths. Figure 6 shows a typical oscilloscope record. (Note that the gauge produced a negative voltage for a positive pressure rise; hence the signal was inverted.) The photograph shows a rapidly rising peak, the signal of interest; this is followed by a complicated interaction of release waves and other signals developed when the drop weight hits the rim of the polyethylene beaker. Again, the pressure/time signature will not be typical of that arising in the eductor, only the initial peak pressure is significant.

The piezoelectric gauges proved to be extremely fragile so that it was not possible to place them in the Fresnel zone of the radiating piston. This was estimated to extend 15 - 20 mm from the piston face. The results shown in Figure 5 demonstrate that pressures as high as 6.7 MPa are generated. Further, the gradient of the line indicates the divergence of the wave and suggest that higher pressures would be expected closer to the impact surface.

If allowance is made for the difference of acoustic impedance of NG compared to that of water we have:

$$Z = \rho U_s \qquad (1)$$

$$Z_{NG} \approx 2.0 \text{ MPa s m}^{-1}$$

$$Z_{H_2O} \approx 1.44 \text{ MPa s m}^{-1}$$

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where Z is the acoustic impedance of the medium; this is derived from the product of the density ρ and the wave velocity U_s.

Now the pressure generated can be shown to be

$$p = \frac{ZZ_s}{Z + Z_s} \, u; \qquad (2)$$

where $Z_s = 39$ MPa s m^{-1}, the acoustic impedance of steel and u is the impact velocity, 4 m s^{-1}. This linear expression holds provided that the hydrodynamic change of density is small. This is valid in the low pressure region we consider here. Hence

$$\frac{p_{NG}}{p_{H_2O}} = \left(\frac{Z_{H_2O} + Z_s}{Z_{NG} + Z_s} \right) \cdot \frac{Z_{NG}}{Z_{H_2O}} = 1.37$$

but $p_{H_2O} = 6.7$ MPa; therefore $p_{NG} = 9.2$ MPa.

The estimated shock pressure p_{NG} is correct provided that the calibrated sensitivity of the gauge is reliable. The calibration equipment produces a pressure relief wave which is two orders of magnitude slower than that of the shock wave. The frequency dependence of the gauge sensitivity is small but finite; it increases slowly with frequency below the resonant frequency of the gauge, which is 10 MHz in this case. It is therefore to be expected that the sensitivity would be slightly higher for the shock wave than the calibration relief wave, so that the value of 9.2 MPa mentioned above is likely to be somewhat too high and the true value may well be quite close to the value predicted by Bascombe,[2] as being capable of leading to initiation under the postulated conditions.

5 CONCLUSIONS

Pressure waves have been generated in a model of the eductor which are commensurate with those predicted by the usual hydrodynamic considerations. Pressures of approximately 6.7 MPa have been measured in water. These are shown to be equivalent to 9 MPa in NG. The measured shock pressure is probably too high because of the frequency dependence of the piezoelectric gauge sensitivity. However it is in close agreement with the predicted pressure in NG of 7.6 MPa.

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The only experimental data available to help us to predict whether shocks of such pressures could initiate NG are those of Roth.[3] In a previous paper[2] an attempt was made to interpret these data in terms of the shock pressure reaching the NG. It must be admitted that his experimental system was complicated and the details given would not be adequate to justify an attempt to repeat his work. There is also no indication in Roth's paper of how many trials were carried out to give the different probabilities of initiation quoted, so that there is no prospect of extrapolating these values to obtain a probability for the much lower shock pressures measured in the present work. Accordingly it cannot be stated whether or not this latter value would approximate even remotely to 1 in 18 000. However, it is felt that the work reported in this paper, by confirming the presence and predicted level of the shock in the eductor, has underlined the need to take this mechanism for the initiation of the Bishopton explosion into serious consideration.

6   REFERENCES

1   Report of the Committee of Inquiry
                                             on the Explosion at ROF Bishopton
                                             Bishopton Report No B923

2   Bascombe K N   Shock Initiation of Nitroglycerine
                                             Containing Air Bubbles
                                             -ibid- Appendix L

3   Roth F J   Sensitization of Liquid Explosives
                                             by Air Bubbles. Proc 36th Int Congress
                                             of Industrial Chemistry, Brussels.
                                             Industrie Chemique, Belge 1967, 32 (2)

4   Harry D W et al   The Characterisation of Water-Driven
                                             Eductors for Greater Safety in Operation
                                             Bishopton Report No B921, April 1976

5   Liddell D A   The Design of Eductors for the
                                             Transfer of Nitroglycerine
                                             between Processing Stages
                                             Bishopton Technical Note No BN 126,
                                             August 1976

6   Johansson C H, Petersson P A   Detonics of High Explosives
                                             Academic Press, London 1970

FIG. 1

KEY

A   WATER ENTERING AT 120 psi
B   JET NOZZLE
C   CAVITY WHERE NG AND WATER
    ARE EMULSIFIED
D   SUCTION LEG
E   NG RISING FROM RESERVOIR
F   STAINLESS STEEL CYLINDRICAL
    SURFACE, SITE OF IMPACT
G   NG/AIR SURFACE
H   PATH OF NG
J   POSITION OF WATER JET

FROM BIAZZI DRG. B-7739
N/G EJECTOR ITEM 130
GIFFARD NO.1
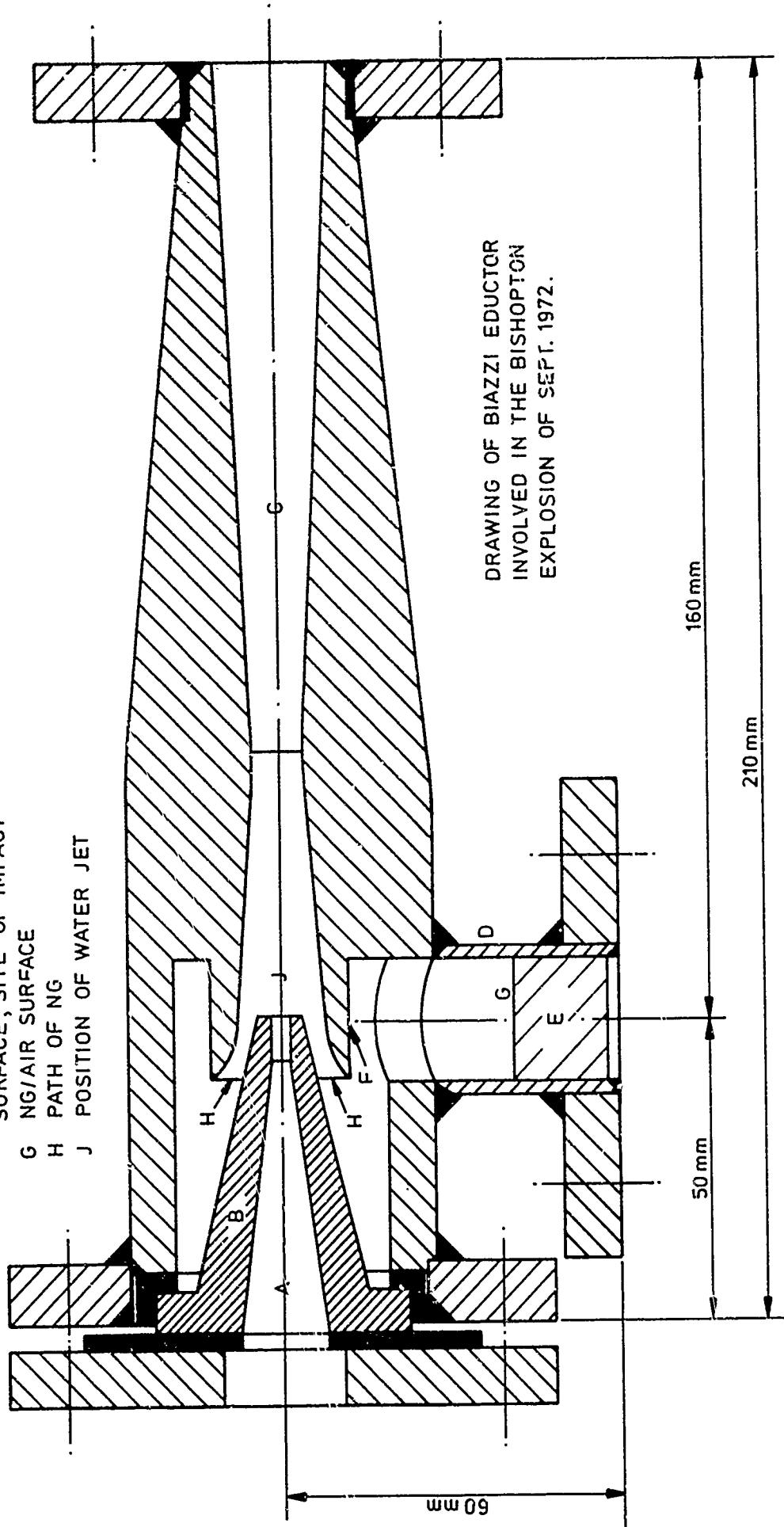
DRAWING OF BIAZZI EDUCTOR
INVOLVED IN THE BISHOPTON
EXPLOSION OF SEPT. 1972.

160 mm

210 mm

50 mm

60 mm

FIG. 1

KEY

A - 5 kg DROP WEIGHT
B - TUFNOL SUPPORT YOKE
C - STAINLESS STEEL IMPACT
    CYLINDER
D - POLYTHENE BEAKER
E - BRASS SHIM EARTHING
    PLATE
F - WATER
G - PIEZOELECTRIC PRESSURE
    GAUGE
H - TRIGGER LEAD
J - EARTH LEAD
S - LIQUID SURFACE

ORIGINAL IMPACT SURFACE
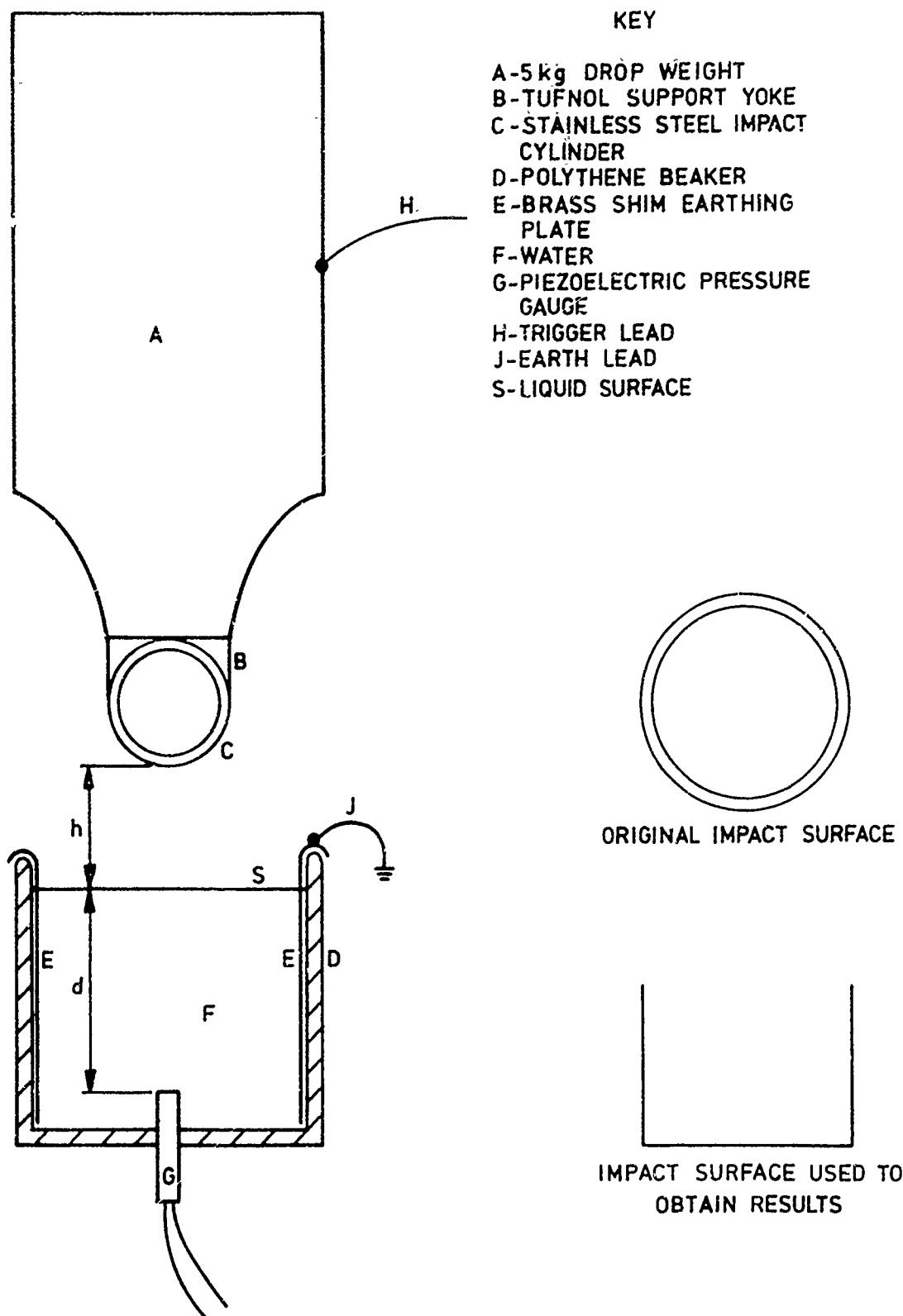
IMPACT SURFACE USED TO
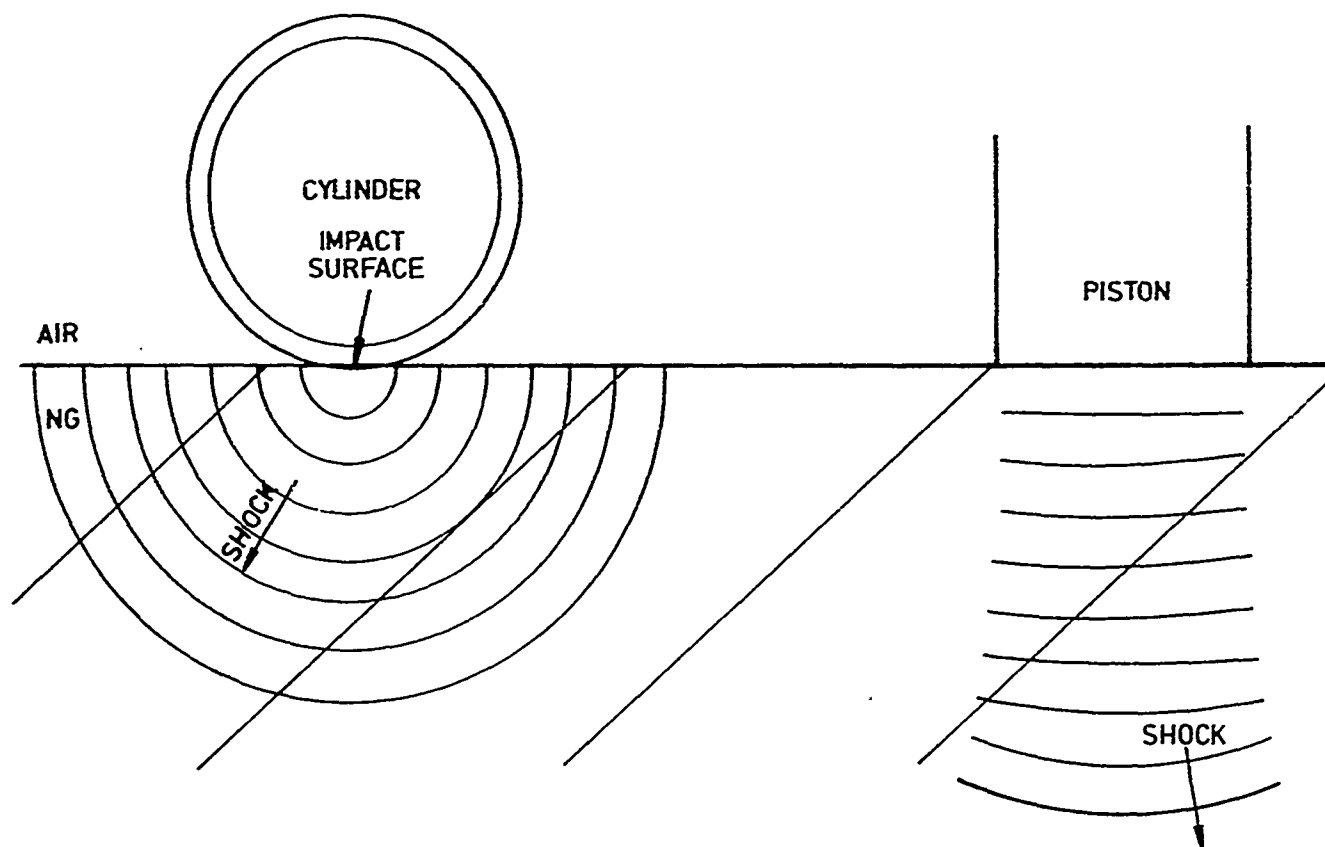OBTAIN RESULTS

FIG. 2   EXPERIMENTAL ARRANGEMENT

FIG. 3 SKETCH OF NG/STAINLESS STEEL IMPACT CONFIGURATION
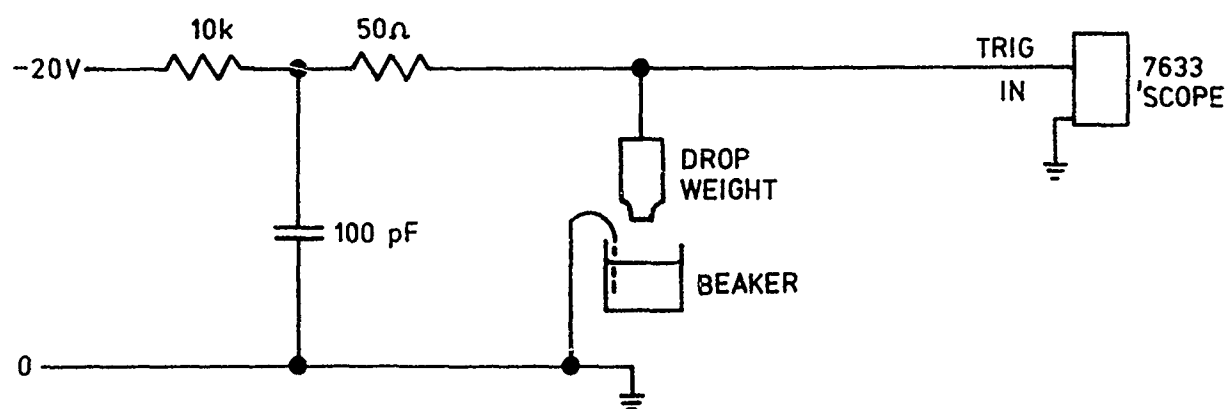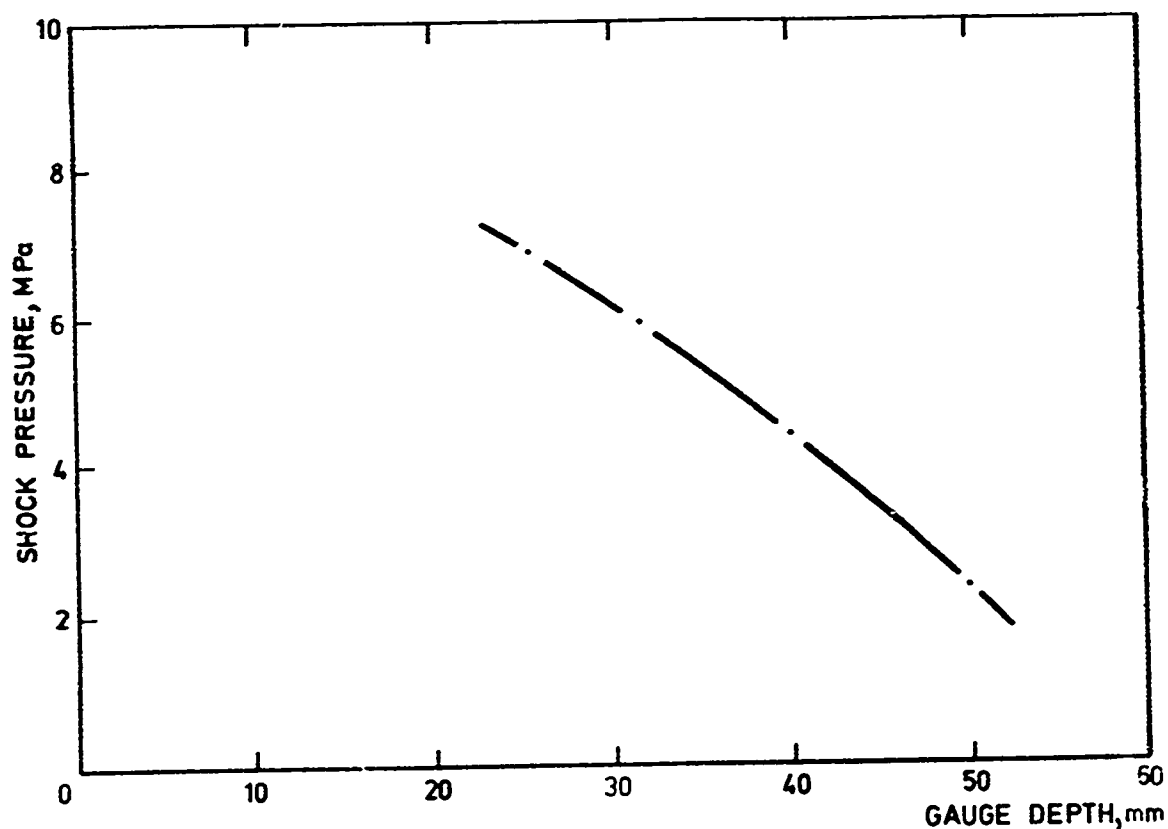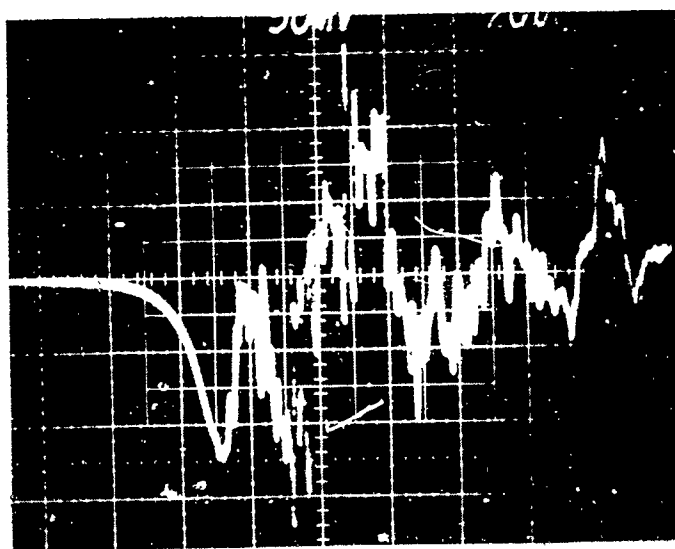

FIG. 4 TRIGGER CIRCUIT

FIG. 5   PRESSURES IN WATER AT VARIOUS DEPTHS

IMPACT VELOCITY $4\,m\,s^{-1}$
GAUGE DEPTH 26 mm
GAUGE SENSITIVITY 22 mV/MPa
Y AXIS 50mV/DIV
X AXIS 20 µs/ DIV

FIG. 6   TYPICAL RECORD

REPORT DOCUMENTATION PAGE

(Notes on completion overleaf)

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5. Originator's Code (if known) 7281400E	6. Originator (Corporate Author) Name and Location Propellants, Explosives and Rocket Motor Establishment Waltham Abbey Essex, England		
5a.Sponsoring Agency's Code (if known)	6a.Sponsoring Agency (Contract Authority) Name and Location		

7. Title

INITIATION OF AERATED NITROGLYCERINE IN AN EDUCTOR

7a.Title in Foreign Language (in the case of translations)

7b.Presented at (for conference papers).Title, place and date of conference

8. Author 1.Surname, initials Tasker D G	9a Author 2	9b Authors 3, 4...	10. Date 10.1979	pp 13	ref 6
11. Contract Number	12. Period	13. Project	14. Other References		

15. Distribution statement

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(TEST)

Abstract

A technique is described for the measurement of the shock wave pressures generated within nitroglycerine (NG), when the liquid surface strikes a steel cylinder. These pressures have been observed in a model of a Biazzi Nitroglycerine Eductor; they are shown to be in close agreement with those theoretically predicted and indicate that this mechanism for the initiation of explosion in NG requires serious consideration.

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